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Contributing to reading comprehension through Science and Technology education

Hanno van Keulen, Windesheim University of Applied Science, The Netherlands
Conny Boendermaker, Windesheim University of Applied Science, The Netherlands

Abstract

In this study, an educational development approach is investigated aiming at improving reading comprehension outcomes in primary education through inquiry and design-based Science & Technology teaching. The context is societal pressure to increase the likelihood that more students, later in their life, will aspire for careers in technology-intensive professions. However, schools are under more pressure to focus on core subjects, such as language. Integrated Science & Technology and Language education may overcome this problem. In this study, students from Years/Grades 3-6 (9- to 12-year-olds) received an experimental treatment, in which regular reading comprehension lessons were replaced by inquiry and design-based projects with a strong focus on oral language. Before and after, their performance on tests for reading comprehension was measured. No significant differences were found from performance in a control group, who received the regular reading comprehension lessons, but hardly any Science & Technology lessons. In the experimental group, teachers used the Skills Rubric Inquiry and Design and reported that students' skills for inquiry and design improved considerably. Substantial professional support in the form of weekly meetings in a professional learning community was necessary to achieve these goals. Initially, the teachers involved had little knowledge of Science & Technology and low self-efficacy with regard to teaching this subject, but teacher attitude towards teaching Science & Technology improved considerably during the project. It was concluded that integrating Science & Technology and language education is a complicated yet rewarding approach.

Key Words

primary education; STEM education; reading comprehension

Introduction and context

In many countries, shortages are reported with respect to technicians and engineers. For example, Ingrid Thijssen, the CEO of Alliander, a Dutch energy company, estimated that, to attain a national target for 2030 with respect to the transition of heating homes with natural gas towards using electricity, the country needs seven times as many technicians than currently enrol in vocational schools (ScienceGuide, 2019). And there are many other challenges and problems for which knowledge, skills and understanding of the material world is required. National and international agencies urge societies to put effort in this area, such as the OECD (2015), the European Commission (2015) and in the USA the National Academies of Sciences, Engineering, and Medicine (2020).

Dutch primary education does not differentiate science and inquiry from technology and design. Problems and questions that arise from interactions with the material world very often have a holistic character, with opportunities for both inquiry ('doing science') and design ('doing engineering and technology'). This is reflected in primary teaching and consequently, in this study, we will refer to the domain with 'Science & Technology'.

Before enrolling in vocational schools or universities of technology, students receive their foundational education in primary schools. Here, an aspiration towards professions relying on Science & Technology may be cultivated, or not (cf. ASPIRES, 2014; Turner & Ireson, 2010). As Lucas, Hanson and Claxton (2104) state about the United Kingdom (p. 3): "Young children are little engineers. Yet the primary school system almost extinguishes any opportunities for them to flourish as engineers." The Netherlands is not quite successful, too, as becomes clear from an analysis of the TIMSS results (Mullis, Martin, Foy, Hooper, 2016, cf. Meelissen et al. (2012) for a secondary analysis of TIMSS data for the Netherlands). Time spent on Science & Technology in primary schools (4%) is one of the lowest in OECD countries as is the percentage of students (13%) that experience the full circle of the phases of inquiry or design-based education. Often, Science & Technology is restricted to unreflected, often decontextualized, making or doing activities, without a proper problem analysis or additional reading. These facts were confirmed by a national survey carried out by the Dutch Inspectorate of Education (2017). Enrolment in degree programs in higher and vocational education that prepare for professions in science and technology in the Netherlands is 25%, and this is far below the OECD average of 40%. Of course, interventions in primary education can only have an indirect effect, but when attitudes and skills are not fostered at an early age, students will not be enabled to make career choices that suit their talents in the domain of Science & Technology. This, however, is not a longitudinal study investigating the ultimate effect of interventions in primary schools on career choices later in life. Rather, it supposes that a certain amount of time and good quality teaching are necessary conditions to attain this objective. In this respect, a survey among primary school principals in the Netherlands revealed that 93% are positive with regard to implementing design and inquiry-based Science & Technology teaching in their schools. Science & Technology education is supported for its importance with respect to participation in society and for its contribution to development of talents of the students. However, an impressive 98% of the principals is of the opinion that their teachers lack the pedagogical repertoire to do this (AVS, 2017).

An important reason for this is that the pressure on primary school teachers primarily comes from language and mathematics. Schools are monitored quite closely in this respect by the Dutch Inspectorate of Education. Schools that perform below average with respect to reading comprehension, taking into consideration the characteristics of their students such as their Social Economic Status, run the risk of interventions and even closing. This is not the case with poor performance in the area of Science & Technology. Partly, this is because there is no national assessment system that measures Science & Technology outcomes. The Netherlands do not have a national curriculum for Science & Technology, only a set of core objectives (Greven & Letschert, 2006). Although several of these are very much to the point (e.g., *'The pupils learn to research materials and physical phenomena, including light, sound, electricity, power, magnetism, and temperature'*, and *'The pupils learn to design, realise and evaluate solutions for technical problems'*), they are also quite generic and difficult to turn into a measurement system, certainly when each school is allowed to try to attain these objectives in its own way. The Dutch Inspectorate of Education tries to estimate Science & Technology teaching quality every six years with a twenty-item multiple choice test (Inspectorate of Education, 2017), but this test does not measure the skills for research or design mentioned in the core objectives. And although the results of this test have been mediocre at best for the past twenty years, no action against schools has ever been taken. Consequently, under these circumstances, primary schools, which have to deal with many other pressing issues, can hardly be blamed not to invest in improving Science & Technology education just for Science & Technology's sake. But this situation also opens a backdoor: if Science & Technology education assists in achieving other objectives, for example difficult language skills like reading comprehension, then Science & Technology could make it to the curriculum. As Axell (2019, p. 89) states in the context of children's literature: "Fictional stories can also be connected to practical activities in technology and prevent technology education from becoming unreflected 'doing' activities." This sets the stage for the present study. Its objective is to explore the contribution that integrated Science & Technology and language education can make to both domains, under regular conditions. This study also explores if this kind of teaching can have a positive impact on teachers' own attitudes and self-confidence with respect to teaching Science & Technology.

Theoretical background

To be able to understand a written text, students first have to be able to decode the strings of symbols. Without knowledge of the letters and how letters build syllables, words and sentences, nothing goes. Experts agree that learning this requires structured, direct instruction and exercise. Typically developing children can acquire this skill when they are 6 or 7 years old (cf. McNamara 2010). Of course, there are important individual differences with regard to many aspects of mastering this skill, and some children are hampered by serious problems such as dyslexia. But that is not the topic of this study. We focus on another element that is important for reading comprehension, which is 'knowledge of the world'. Texts, in general, refer to things, events and situations in the world, and knowledge of these things, events and situations helps to understand the meaning of the text (Hirsch, 2003), as much as reading helps to develop a conceptual understanding of the world (RAND Reading Study Group, 2002). Research has shown that such concept-oriented reading instruction has a positive effect on strategy use and text comprehension (Guthrie, Van Meter, Hancock, Alao, Anderson & McCann, 1998).

In general, children acquire knowledge of the world through direct experience, often in combination with hearing the oral language that is uttered in the context. Oral language is an outcome of this interaction with the world and the need to communicate adequately with others (cf. Enfield, 2015; De Ruiter & Theakston, 2017). Conceptual or scientific understanding also is an outcome of this activity (Osborne, 2010). This opens a venue towards Science & Technology education. After all, Science & Technology education, certainly in the format of inquiry or design, is all about sensing, acting, exploring and experiencing the material world, with the implicit or explicit intention to understand this world and develop the knowledge and skills that are needed for direct survival, problem solving, meaning making and communicating with others. Consequently, for teachers in primary schools, exploring and communicating about the material world and using inquiry and design-based teaching formats could be a means to improve reading comprehension outcomes, through improved knowledge of the world and development of linguistic registers. It would allow schools to put Science & Technology on the timetable without the need to skip other subjects.

Indeed, there are many indications that Science & Technology learning and language learning benefit from each other. Guthrie, McRae and Lutz Klauda (2007) found positive outcomes for students' science and reading achievement in an integrated approach. Vitale and Romance (2012) found that prior science knowledge helped to understand the meaning of texts. Reiser, Berland and Kenyan (2012) showed that oral discussions contribute to students' achievements by promoting sharing, critical analysis and collective reasoning about science practices. Lee, Quinn and Valdés (2013) see possibilities for common core standards for English language in relation to the USA's Next Generation Science Standards. Hand, Norton-Meier, Gunel and Akkus (2016) showed that students' argumentation skills profited from embedding language in primary science classrooms. Snow (2010) and Lin (2019) see development of domain specific academic language registers. However, positive effects have often been found through controlled interventions in which researchers were in the lead with respect to designing the educational materials and conducting the lessons (cf. Cervetti, Barber, Dorph, Pearson & Goldschmidt, 2012). Integrating Science & Technology and language teaching is a difficult pedagogic skill, as is inquiry or design-based teaching, and teachers need support to develop these skills (Gresnigt, Taconis, Van Keulen, Baartman & Gravemeijer, 2014). Moreover, most primary school teachers are not specialists with regard to Science & Technology: their content knowledge of Science & Technology disciplines is shallow, and many teachers regard themselves as 'non-tech'. Asma, Walma van der Molen and Van Aalderen-Smeets (2011) related teachers' apprehensive attitudes towards science and technology to students' interest. Teachers typically find it difficult to inspire their students towards Science & Technology (cf. Turner & Ireson, 2010; Potvin & Hasni, 2014; YoungWorks, 2016). This certainly is true of the average primary school teacher in the Netherlands. To develop teacher attitude towards Science & Technology and develop difficult teaching skills, substantive professional development is necessary. Promising approaches in this respect have teachers collaborate in communities of practice and give them the role of co-designers and co-researchers (Clarke & Hollingsworth, 2002; Stoll, 2015; Binkhorst, 2017).

Aim of this study

The aim of this study is to develop an approach that, from the point of view of primary schools, allows teachers to improve reading comprehension outcomes through inquiry and design-based teaching, and, from the point of view of modern, technological society, improves the likelihood that students aspire for higher education programs and careers in Science & Technology. We conjecture that substantive professional development is necessary for this.

We aim for a 'proof of concept study' in which we conjecture that the approach is valid if:

a) The project is carried out in a setting that is representative of primary schools and teachers in the Netherlands, with the addition of professional development support.
b) Reading comprehension skills of the students involved are better, or at least the same, as the skills of students from a control group that receives traditional reading comprehension lessons.
c) Students involved have or develop a positive attitude for Science & Technology and improve their skills for inquiry and design.
d) Participating teachers and schools feel empowered to teach integrated Science & Technology and Language lessons and continue doing this after the end of this research project.

Methods

In order to investigate our conjectures, we carried out a research project called 'Flywheels for reading comprehension', with financial support from the Dutch Research Council (NWO), grant 405-15-503. The experimental work was carried out in two primary schools in the city of Lelystad. Lelystad is a middle-sized city in the middle of the Netherlands. One of the experimental schools had students with average Social Economic Status (SES), one with SES well below average. Both schools are from the same School Board and share the principal and the remedial teacher. The project was carried out from 2014 (conception of the project) till 2017 (data analysis and final reporting). Data pertaining to students were gathered in 2015. The grant allowed the schools to reschedule the teaching workload, hire substitutes and enable several teachers to participate substantively in the project.

We formed a professional learning community (PLC) with the five classroom teachers who taught the upper Years/Grades (the 9- to 12-year-olds); the remedial teacher; and a researcher (the second author). All but one of the teachers were female. Their teaching experience ranged from three years to twenty. All but one initially described themselves as 'non-tech'. None had experience with inquiry or design-based teaching. The students came from four classes (one class had two teachers), compatible to UK Year/US Grade 3, 4, 5, and 6. One class was a mixed classroom 8- and 9-year-olds. We focused on the 9- to 12-year-olds and left out the data of the 8-year-olds.

The PLC met every week for three hours, first to develop a basic understanding of inquiry and design-based Science & Technology teaching, second to develop integrated lesson series on Science & Technology and reading comprehension, and third to discuss and reflect on the outcomes and on what had happened during the lessons. Occasionally, experts from the areas of Science & Technology or linguistics joined the PLC. Two lesson series, each of about 13 weekly lessons of approximately two hours, were designed and conducted by the teachers in their classes. The first lesson series was on how rivers flow and how dykes can be designed to contain the water, using a purpose-made sand-and-water table (Figure 1).

Figure 1 An experiment on how rivers flow

Water management is very important for the Netherlands and relies on many Science & Technology-related vocations. It is a meaningful context for students and easily links to their life world and daily experiences. The idea, information with respect to content knowledge, suggestions for lessons, and the sand-and-water table were provided by the research team on the basis of hydromorphological research carried out at the Faculty of Geosciences of Utrecht University (cf. Kleinhans et al. 2014; Van Wessel, Kleinhans, Van Keulen & Baar, 2014). The second lesson series was developed with the teachers in the lead and with less additional expert support. The theme of this series was ‘Light and Vision’.

The point of the lessons series was that the students should explore material phenomena and solve technical problems. They were supposed to discuss their pre-knowledge, develop ideas, explanations, plans and reflect on findings in oral discourse with each other and with the teacher. The focus was very much on oral language. The teacher also stimulated that students should read about the topic. To achieve this, the school library in cooperation with the municipal library provided books that students could read (Figure 2).

Figure 2 Reading about light and vision

The researcher visited approximately ten percent of the lessons and, when appropriate, made video recordings for use in the PLC and for qualitative analysis. The Science & Technology lessons took the place of lessons normally devoted to reading comprehension, so no additional teaching time was involved. In order to estimate outcomes, we used several instruments. To be able to compare outcomes, two schools were involved as a control. These schools employed a standardized, commercially available approach to teach reading comprehension, which is quite regular in the Netherlands. The same material used to be used by the experimental schools.

To investigate reading comprehension, we used the school's longitudinal data base information on reading comprehension from the 'Cito LeerlingVolgSysteem Begrijpend Lezen'. This is a validated instrument with a five-point scale used widely in the Netherlands. We used this information to benchmark the individual students as 'weak' (score 1), 'average' (scores 2-4) or 'strong' (score 5) with respect to reading comprehension.

We used two tests on two different topics (called 'Fly, Eagle, Fly' and 'Discover the Fun of Day Hiking') from the international PIRLS study on reading comprehension (Mullis, Martin, Foy & Drucker, 2012) to test students' growing ability during the project. Half of the students took 'Eagle' as pre-test and 'Day Hiking' as post-test, for the other half the reverse design was used, in order to control for test differences. In order to estimate the effect of 'knowledge of the world' we constructed a new test with texts on the topics the students had investigated. We called this the Sand-Water-Light (SWL) test. We used exactly the same format as the official PIRLS tests, in order to be able to compare scores on the SWL-test to generic scores. The time between pre-test and post-test was six months.

To estimate the students' attitude towards Science & Technology we used the Pupils' Attitude Towards Technology (PATT) instrument in the Dutch language version of Ardies, De Maeyer, Gijbels and Van Keulen (2014). The PATT is a five-point Likert scale questionnaire containing items on aspirations, interest, consequences, difficulty, enjoyment and gender.

To estimate students' skills for inquiry and design teachers scored a sample of their students using the Skills Rubric Inquiry and Design (SRID). This is a high-inference instrument with the scores based on accumulated classroom observations. The SRID was developed and validated in a pilot study in the Netherlands (Van Keulen & Slot, 2014) but has not been published in the English language. Therefore, the instrument is made available in Appendix 1. The SRID has two independent rubrics, one on inquiry and one on design. Both are divided into nineteen items and five scales, according to the stages and sub-skills for the inquiry or the design process (cf. Pedaste et al., 2015) and the underlying five psychological constructs, that is, skills for curiosity – skills for creativity – skills for executing plans – skills for critical thinking – skills for communication (Van Keulen, 2015). The SRID has four additional items on attitudes and other relevant skills (Enjoyment; Initiative; Social and Communicative Skills; Creativity and Originality). Each item has three performance categories (unsatisfactory; satisfactory; excellent) and each cell contains feedback suggestions a teacher might give to the student. In order to enable quantitative analyses, numerical scores can be given too, using a seven-point scale (unsatisfactory = 1-2; satisfactory = 3-5; excellent = 6-7).

To estimate teachers' attitude towards Science & Technology we used the Dimensions of Attitude towards Science (DAS) (Van Aalderen-Smeets & Walma van der Molen, 2013). The DAS is a five-point Likert scale questionnaire with three dimensions: 'Cognitive Beliefs' (with the factors 'Perceived Relevance', 'Perceived Difficulty' and 'Gender Beliefs'); 'Affective States' (with the factors 'Enjoyment' and 'Anxiety'); and 'Perceived Control' (with 'Self-efficacy' and 'Context Dependency'). The DAS has two sets of items, in order to measure both professional attitude (pertaining to classroom teaching) and personal attitude (pertaining to daily life). It also has questions on predispositions to act in personal and professional life (Behaviour Disposition Personal and Professional).

In order to estimate the effectiveness of the whole approach teachers kept a journal. The PLC-discussions were logged. The researcher made field notes when observing lessons. These sources of data were analysed qualitatively, following the principles of Educational Design Research (McKenney & Reeves, 2012) with open coding and inductive analysis (Saldaña, 2015), and using De Groot's (1974) categories for analysing learning reports. De Groot urges to pay attention to learning experiences pertaining to rules, like: "I have learned that it is important to start with taking stock of what the children already know about the topic", and exceptions to rules, like: "Most children are eager to say what they think is happening, but some children need encouragement". De Groot also emphasizes the importance of learning experiences that express surprise about the world or oneself, like: "I hadn't realized that water flows faster in the outside bend of a river", and: "I was surprised that there could be so much content-oriented talk during experiments".

A summary of the instruments and the participants is presented in Table 1. As is visible in the table, numbers on pre- and post-tests differ slightly, mainly due to illness of students and to pregnancy, in the case of the teachers.

Table 1 Summary of instruments and number of participants

	Pre-tests				Post-tests			
	PIRLS	PATT	SRID	DAS	PIRLS + SWL	PATT	SRID	DAS
Students experimental schools	71	73	8		69	67	8	
Students control schools	60	68	-		55	-	-	
Teachers experimental schools				5				4
Teachers control schools				8				-

Results and conclusions

Students' reading comprehension

The outcomes with respect to reading comprehension test scores are expressed in Table 2. We first compared the mean standardized scores on the PIRLS pre-test of the experimental group with the control group (Table 2, A).

Table 2 Comparison of reading comprehension scores

	A: Pre-test PIRLS			B: Post-test PIRLS			C: SWL-test		
	N	Mean	Standard deviation	N	Mean	Standard deviation	N	Mean	Standard deviation
Experimental group	71	.88	.328	67	.93	.323	67	.55	.167
Control group	60	.98	.283	66	1.05	.294	66	.59	.137
Total	131	.92	.312	133	.99	.314	133	.57	.154
	p=.048 (significant for *p*<.05)			*p*=.020 (significant for *p*<.05)			*p* =.131 (not significant for *p*<.05)		

The schools draw their students from different districts, with different characteristics such as SES. This is reflected in the scores: the control group scores significantly better. We then compared the scores on the PIRLS post-test. Again, the control group scored significantly better (Table 2, B). Next, we compared the growth in reading comprehension as the difference between pre- and post-test between the experimental group and the control group. This difference proved to be not significant, implying that the experimental group had improved as much as the control group, apparently on the basis of oral discussions and reading out of interest.

We also compared the scores on the Sand-Water-Light (SWL) test. The mean scores on this test are expressed as percentage of correct answers, since this is a unique test that is not standardized, as are the PIRLS tests. Here, the difference between the experimental group and the control group was not statistically significant (Table 3, C). Given the significant difference in reading comprehension competence on generic texts (PIRLS) between the two groups, we take this outcome as an indication that 'knowledge of the world' does indeed contribute to reading comprehension, and that Science & Technology lessons with a focus on oral language are a means to develop reading comprehension skills. We also tried to make comparisons within the experimental group between strong, average and weak readers to find out which sub-group benefited most from the experimental condition, but due to small numbers of both strong and weak readers, this analysis failed to pinpoint any significant effects.

Students' attitude for Science & Technology

The scores on students' attitude for Science & Technology were measured with the PATT. The attitude of the experimental group is presented in Table 3. Table 4 presents the comparison with the control group.

Table 3 Attitude for Science & Technology for the experimental group

	Pre-test (n=61)		Post-test (n=61)		Comparison	
	Median	Range	Median	Range	Z	p
Aspiration	2,67	3,00	3,00	3,50	1,680	0,093
Interest	3,00	2,50	3,00	2,50	0,994	0,320
Consequences	2,00	3,00	2,33	3,00	0,799	0,424
Difficulty	3,00	3,50	3,00	4,00	1,354	0,176
Gender	4,00	4,00	3,67	4,00	0,684	0,494
Enjoyment	3,50	2,75	3,33	2,25	-0,930	0,352

Table 4 Comparison of attitude scores between experimental and control group

	Experimental group (n=61)		Control group (n=68)		Comparison		
	Median	Range	Median	Range	U	z	p
Aspiration	3,00	3,50	2,83	3,33	2007,500	-0,156	0, 876
Interest	3,00	2,50	2,88	2,75	1887,000	-0,738	0, 461
Consequences	2,33	3,00	2,00	3,00	1397,500	-3,120	0, 002*
Difficulty	3,00	4,00	2,75	4,00	1666,000	-1,795	0, 073
Gender	3,67	4,00	3,00	4,00	1499,000	-2,598	0, 009*
Enjoyment	3,33	2,25	3,25	3,00	1926,500	-0,548	0, 583

*significant *p*=<.05

As can be seen in these tables, the students are quite positive with respect to Science & Technology. They think it is important and enjoy the lessons. They are neutral with respect to difficulty, interest and their aspirations. They disagree that Science & Technology is more appropriate for boys than for girls. These positive attitudes did not change much during the intervention. Also, students in the control group did not differ much in attitude. Clearly, it is not because of the attitude of these students that Science & Technology plays a minor role in their schools.

Students' skills for inquiry and design

In both the experimental and the control schools, Science & Technology education was almost absent on the timetable. Typical activities ranged from collecting chestnuts in autumn to watching a video on robotics. None of the teachers involved was acquainted with inquiry or design-based education. It had been established that teachers with experience in inquiry and design-based teaching needs four to five minutes to score one student with Skills Rubric Inquiry and Design (SRID). Teachers that are not only inexperienced with the instrument but also unfamiliar with the behaviour of students in inquiry or design-based education, need a lot more time and their observations may also not be very reliable. We decided not to use the SRID in the control group, and to limit the use of this instrument to a small sample of students in the experimental group, in order not to overwhelm the teachers. Three of the teachers each scored three of their students, who were selected on the expectation that they would respectively be weak, average and strong in inquiry and design. One of the students dropped out due to illness, so the eventual analysis is based on 8 students, who were scored in the beginning of the project and at the end. Teachers also did not score all (2 times 19) items but limited themselves to the five categories pertaining to the stages of inquiry and design, and the attitudes. The scores are presented in Table 5.

Table 5 Scores on the Skills Rubric Inquiry and Design (1- to 7-point Likert scale)

	Pre-test (n=8)		Post-test (n=8)		Comparison	
	Median	Range	Median	Range	Z	p
D: Design	3,70	3,60	4,60	3,40	2,038	0,042*
D1: Problem recognition	4,00	4,00	5,00	3,00	2,070	0,038*
D2: Designing a solution	3,00	4,00	4,50	5,00	1,947	0,052
D3: Realising the design	4,00	2,00	4,50	3,00	1,134	0,257
D4: Testing and improving	3,50	4,00	4,50	3,00	1,200	0,230
D5: Presenting	3,00	4,00	4,50	4,00	2,266	0,023*
I: Inquiry	3,70	3,80	4,10	3,40	1,680	0,093
I1: Curiosity and hypothesizing	5,00	4,00	5,00	4,00	1,265	0,206
I2: Gathering data to answer the question	3,50	4,00	4,00	3,00	1,725	0,084
I3: Analysing data	3,50	5,00	3,50	5,00	1,211	0,226
I4: Drawing conclusions and critical reflection	3,00	4,00	4,00	4,00	1,852	0,064
I5: Presenting	3,00	4,00	4,00	4,00	1,552	0,121
A: Attitudes and other skills	4,00	4,00	4,75	3,50	0,594	0,553
A1: Enjoyment, interest and motivation	5,00	3,00	6,00	3,00	0,638	0,524
A2: Initiative and executive functioning	3,50	5,00	4,50	4,00	0,954	0,340
A3: Communicative and social attitude	4,00	6,00	4,50	5,00	0,604	0,546
A4: Creativity and originality	5,00	3,00	4,00	3,00	-0,816	0,414

*significant p=<.05

Given the complications with scoring these skills and the small number of students, we cannot really draw reliable conclusions with respect to the development of skills for inquiry and design. However, as can be seen in the table, the teachers were of the opinion that all students improved greatly. This they also expressed in the professional learning community. They were surprised how much all students enjoyed the lessons, even those who did not regularly show involvement in scholarly work. Also, the teachers evaluated the instrument positively. It helped them, they said, to understand better what inquiry and design-based teaching is about, and how to observe their students in new ways in the future.

Teachers' attitude towards Science & Technology

The scores for teachers' attitude towards Science & Technology, as measured with the DAS, are presented in Tables 6. Comparisons with the control group are made in Table 7.

Table 6: Development of attitude towards Science & Technology in the experimental group (DAS)

	Pre-test (n=5)		Post-test (n=4)		comparison	
	Median	Range	Median	Range	Z-score	p
Cognitive belief personal						
Perceived relevance	3,50	0,75	3,375	1,00	0,378	0,705
Perceived difficulty	4,50	2,75	4,00	3,00	-0,707	0,480
Gender Beliefs	3,00	2,50	2,50	3,00	-0,365	0,715
Cognitive belief professional						
Perceived relevance	4,00	1,00	4,10	0,80	0,000	1,000
Perceived difficulty	4,00	1,34	3,835	1,67	-1,089	0,276
Gender Beliefs	2,75	2,75	2,875	0,75	-0,365	0,715
Affective states personal						
Enjoyment	4,00	1,00	3,875	2,00	0,000	1,000
Anxiety	3,50	2,75	3,00	3,00	0,816	0,414
Affective states professional						
Enjoyment	3,25	0,75	4,00	2,50	0,447	0,655
Anxiety	3,25	3,25	2,00	3,00	-1,604	0,109
Perceived Control personal						
Self-efficacy	2,75	0,75	2,875	1,50	0,378	0,705
Context Dependency	3,00	1,33	3,165	2,66	-0,378	0,705
Perceived Control professional						
Self-efficacy	3,00	2,00	3,10	1,80	1,461	0,144
Context Dependency	4,00	2,33	3,50	2,67	-1,633	0,102
Behavioural disposition personal	2,17	1,50	2,25	1,34	-1,069	0,285
Behavioural disposition professional	1,71	0,43	3,07	1,14	1,841	0,066

Table 7: Comparison of attitude towards Science & Technology between experimental and control group

	Experimental group (post-test) (n=4)		Control group (n=8)		Comparison		
	Median	Range	Median	Range	U	Z-score	p
Cognitive belief personal							
Perceived relevance	3,375	1,00	3,00	0,75	6,50	-1,729	0,084
Perceived difficulty	4,00	3,00	3,25	1,75	10,50	-1,398	0,162
Gender Beliefs	2,50	3,00	3,125	3,00	14,50	-0,257	0,797
Cognitive belief professional							
Perceived relevance	4,10	0,80	3,20	1,60	3,00	-2,235	0,025*
Perceived difficulty	3,835	1,67	3,165	1,67	5,00	-1,892	0,059
Gender Beliefs	2,875	0,75	2,50	2,75	8,00	-1,378	0,168
Affective states personal							
Enjoyment	3,875	2,00	3,75	2,25	12,00	-0,695	0,487
Anxiety	3,00	3,00	2,50	2,50	13,50	-0,426	0,670
Affective states professional							
Enjoyment	4,00	2,50	3,00	2,50	7,50	-1,462	0,144
Anxiety	2,00	3,00	2,375	2,75	14,50	-0,260	0,795
Perceived Control personal							
Self-efficacy	2,875	1,50	2,50	2,50	15,00	-0,174	0,862
Context Dependency	3,165	2,66	2,67	1,33	10,00	-1,041	0,298
Perceived Control professional							
Self-efficacy	3,10	1,80	3,10	2,00	14,50	-0,256	0,798
Context Dependency	3,50	2,67	3,50	2,00	14,50	-0,261	0,794
Behavioural disposition personal	2,25	1,34	2,00	1,50	11,00	-0.868	0,386
Behavioural disposition professional	3,07	1,14	1,71	1,00	0,00	-2,737	0,006*

*significant *p*=<.05

The DAS is an instrument that is validated for large numbers, but this study focuses on a small number of teachers, implying that any differences have to be huge in order to become statistically significant. So, we concentrated on the absolute findings and add qualitative information from the reflective discussions in the professional learning community (PLC) to the interpretation.

Clearly, the experimental teachers showed signs of apprehension in the pre-test. They knew they were going to do something new, which they perceived as important and good to do but also as difficult. Both Professional Perceived Relevance and Professional Difficulty come out high. An effect of the intervention is clearly visible in the data: Professional Behaviour Disposition grew from 1.71 to 3.07, whereas Professional Anxiety was reduced from 3.25 to 2.00. Teachers also feel less dependent upon help from the context. This interpretation was confirmed by the teachers in the PLC. They expressed that they were more and more looking forward to the lessons, and that teaching became less difficult and more enjoyable. One teacher, for example, expressed that she had learned that it is not necessary to know all about Science & Technology, and that not knowing things can even be beneficial because it makes the investigation more interesting to the students and makes it easier to adopt a coaching role. The teachers appreciated the discussions and exchange of ideas and experiences in the PLC and stated that this helped them to overcome anxieties towards Science & Technology teaching. We conclude that professional development, co-designing and reflective discourse in a PLC contributed to developing a positive professional attitude towards Science & Technology teaching.

Qualitative findings with respect to integrating Science & Technology and language

Initially, the teachers had no intention to integrate Science & Technology and language in their lessons. It was the principal of the school who convinced them to take part in the experiment and try out something new. Schools in the Netherlands typically use different textbooks for every individual subject; integration runs against this practice. Although the teachers did not deny that oral discussions about material phenomena such as water management could help contribute to building a domain specific and academic vocabulary and to other language skills, they could not easily relate this to the highly structured learning progressions prescribed by the textbooks on reading comprehension. They feared that leaving out the normal reading comprehension lessons would result in weak test scores and thus put their professional credibility into question. They were relieved that the post-test scores were as good as they should be, but during the project they also became convinced that the integrated approach had other merits. They had feared that they would lose control, and indeed this happened once in a while, but they also noticed that students assumed control, were far more involved and ‘time on task’ was higher than in a typical direct instruction reading comprehension lesson. They noticed the power of material phenomena, such as a dyke that collapses under the pressure of water, to draw attention, provoke curiosity and sparkle off discourse and a hunger for explanations. Students who were normally not motivated to read now became more interested readers on the topics of the lessons. Importantly, the teachers’ skills for scaffolding group discussions improved with experience. Teachers became better in asking questions, involving all students, summarizing, and drawing conclusions. One teacher stated that she started using this scaffolding and discourse repertoire in other lessons as well. Also, teachers’ conceptions of reading comprehension developed. Whereas at the start of the project they did not relate reading comprehension to knowledge of the world and oral discourse, at the end they were able to explain to colleagues how domain specific knowledge acquired through experience and discourse can have an impact on vocabulary, reasoning styles, and the understanding of texts.

Implementation and proof of concept

We conjectured that this approach would proof the concept of integrated Science & Technology and Language Education if (1) participating teachers and schools felt empowered to teach integrated Science & Technology and Language lessons and continue doing this after the end of this research project; if (2) reading comprehension skills of the students involved were better, or at least the same, as the skills of students from a control group that receives traditional reading comprehension lessons; and if (3) the students involved had or had developed a positive attitude for Science & Technology and improved skills for inquiry and design. We conclude that these criteria were met. The approach became indeed implemented in the normal routine of one of the schools, with new incoming teachers learning through co-teaching from their peers. Although the Netherlands currently has teacher shortages and a huge turnover, and all participants except one have left the school at the moment of writing this article (2019), the integrated Science & Technology and reading comprehension module still is firmly in place, and test results for reading comprehension have started to increase. The control schools, and most other schools in the vicinity, however, although they were informed and supplied with all lesson plans and other materials, remained apprehensive towards integrating Science & Technology and reading comprehension. This is in line with our last conjecture, namely (4) that substantial professional development, such as provided in a Professional Learning Community, is necessary. This study thus affirms that it is possible to integrate inquiry and design-based Science & Technology teaching with reading comprehension with good results for both subjects, and in a setting that is representative of primary schools in the Netherlands.

Discussion

This study confirms that Science & Technology education can contribute to the development of linguistic skills, such as reading comprehension. It adds to the theoretical framework by exploring issues of implementation in regular practice. The design of this study allowed more ownership to teachers than in many other experimental designs, leading to lasting implementation: the teachers themselves co-designed the lessons, carried out these lessons, reflected on the experiences and became conscious of their expanded repertoire. They found ways to implement the approach in their school's curriculum, being able to take into account the idiosyncrasies that characterize each and any individual school. Although the teachers were not selected randomly, they were not biased in favour of Science & Technology. On the contrary, their knowledge and self-efficacy was weak at the outset but developed during and on behalf of this project.

To achieve this, a substantive in-service professional development program was necessary. This requirement had consequences for the possibilities to quantify outcomes and draw conclusions that are wider than pertaining to this small population of teachers and students. A power analysis on the basis of the magnitude of the effects that were found suggests that at least 300 students would have been necessary to generate differences that are of statistical significance, and which would also have allowed us to discriminate between weak, average and strong readers. However, this would have meant a fivefold increase of the cost of the project, since it

is not the development and conduct of the lessons that takes so much time, but the many meetings in the professional learning community. Although all lesson plans and reports were made available to the control schools and all other schools in the district, none of these started with integrated language and Science & Technology lessons on their own. Apparently, development of positive attitude towards Science & Technology, especially with respect to professional perceived control (self-efficacy and context-independency), is a prerequisite.
The Netherlands are quite unique compared to most other countries for its absence of a prescribed curriculum and national testing for Science & Technology, in combination with core objectives that are not very specific. This allows schools professional freedom and autonomy and could, in principle, lead to excellent teaching quality and to good learning outcomes. However, this is not the case. Without a curriculum, without clear standards, without inspection, and with many other challenges competing for time and effort, this system is not working for Science & Technology. The Netherlands has approximately 6,000 primary schools and 125,000 teachers, and many do an excellent job, but the countrywide results with respect to Science & Technology are disappointing.

Inquiry and design-based Science & Technology education, as well as integrative teaching, require advanced pedagogic skills. The foundations for this are laid in the teaching certificate programs, which in the Netherlands is at the bachelor's level. Apparently, this is not enough. Alternative approaches, leading to higher professional qualifications can be found in countries that serve their primary schools with degree programs at the master's level or stimulate teachers to specialize in a subject, e.g., the arts, mathematics, or Science & Technology. Does Science & Technology education require a master's level and/or subject specific qualification to be successful? Which country is doing really well on Science & Technology, and what are the investments and trade-offs?

There is, however, another side to this coin. When reading comprehension skills can be advanced through Science & Technology, and both students and teachers are satisfied with this, then teaching Science & Technology education is a strategy to meet educational challenges from other domains. If this approach works for reading comprehension, it may work for citizenship, for entrepreneurial thinking, for the arts, or for special needs education. From this point of view, learning about Science & Technology is a bonus for schools who invest in integration.

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Appendix 1 Skills Rubric Inquiry and Design

Skills Rubric Inquiry			
	Unsatisfactory (1-2)	*Satisfactory (3-5)*	*Excellent (6-7)*
Curiosity / exploring the problem			
I1.1. Asking questions	Doesn't ask questions. Appears not to be interested.	Appears to be curious. Asks questions that relate to observations ('What is that?'; 'Why is the sky blue?')	Asks many questions. Shows an eagerness for knowledge. Is interested in relationships between observations. Asks questions based on reasoning.
I1.2 Using previous knowledge	No signs that existing knowledge, skills or experiences are used.	Draws explicitly on previous knowledge and experiences.	Has knowledge on many subjects and shows this. Easily relates new experiences to previous knowledge.
I1.3 Problem exploration	Doesn't explore the problem. Is passive. Is not committed to the inquiry task.	Explores intuitively. Looks; feels; tries; uses sensorimotor experiences. Seeks on the internet or uses other sources.	Explores systematically. Can provide clear reasons for exploring this way. Is not afraid to try new ways. Has specific expectations. Poses focused questions. Finds good sources of information.
I1.4 Confining the problem	Doesn't bother whether the problem is too big or complicated to investigate.	Transform the initial problem into a research question. Is explicate about the focus of the inquiry.	Knows how to confine problems. Is explicit about what is most and what is less important to investigate. Provides reasons for choices.
I1.5 Expectations	Has no specific expectations. Doesn't take into account possible constraints.	Is explicit about what to expect as an outcome of the inquiry.	Is explicit about what to expect. Bases expectations on previous knowledge and logical thinking. Takes constraints and circumstances into account.
Creativity / designing activities to answer the research question			

I2.1 Making a plan	Doesn't know what to do to answer the question Doesn't make a plan.	Comes up with ideas how to answer the question. Designs experiments. Has a plan.	Designs an experimental plan that covers all questions. Takes issues of validity and reliability into account.
I2.2 Conducting experiments	Doesn't stick to the plan when investigating.	Conducts the experiments and other ways to gather data according to the plan.	Carries out the plan carefully and compares outcomes to expectations. Repairs mistakes.
I2.3 Observing	Doesn't pay attention to what is observable.	Is attentive. Concentrates on what is to be observed.	Observes systematically. Is not easily distracted. Has an eye for the unexpected. Sees relationships between observations.
Executive functions /Gathering data and transforming observations into results			
I3.1 Capturing data	Hardly takes notes. Cannot reconstruct observations. Commits errors when capturing data. Needs help.	Captures data according to plan. Doesn't make mistakes. Can recapitulate the observations.	Captures data systematically and unequivocally. Takes notice of phenomena that were unexpected. Recapitulates the observations clearly and completely.
I3.2 Data handling	Doesn't structure the data. Doesn't elaborate on raw data.	Structures the data. Provides tables, charts, drawings or other elaborations.	Structures and elaborates on the data correctly and adequately. Notices outliers and contradictory evidence.
I3.3 Focusing on the essentials	Is clueless with respect to what is important.	Knows what is essential and what are the minor points	Clearly differentiate major and minor issues. Uses the research question to prioritize.
Critical thinking / Concluding and discussing			
I4.1 Drawing conclusions	Cannot see if the research question has been answered.	Draws conclusions on the basis of the results. Compares	Presents results and conclusions as answers to the

	Focuses on what has been done and not on outcomes.	outcomes with expectations.	research questions. Draws inferences that are credible. Builds on existing theory.
I4.2 Critical reflection	Doesn't use criteria to reflect on the outcomes and conclusions.	Discusses whether the conclusions are credible. Leaves room for alternative explanations.	Uses criteria such as theoretical grounding, (statistical) significance, limitations and practical relevance to evaluate conclusions. Looks actively for alternative explanations. Makes suggestions for further research.
Communicating			
I5.1 Preparing a presentation	Is unable to prepare a presentation that covers the research design.	Is able to prepare an oral or written presentation that covers the problem, the research design, the results and the conclusions.	Is able to prepare a presentation the whole inquiry process in various oral and written formats. Adequately uses visuals and other media. Clearly presents hypotheses, research questions and conclusions.
I5.2 Giving a presenting	Presents in a way that doesn't adequately communicate the investigation.	Presents the initial problem, the research design and the most important outcomes adequately.	Covers the whole research. Provokes the curiosity and interest of the audience or readers. Handles questions, critique and feedback well.
D5.3 Implications	Doesn't focus on implications and further research.	Pays attention to potential consequences and actions that logically follow from the study.	Pays attention to how the study contributes to practice and/or theory.

Skills Rubric Design			
	Unsatisfactory (1-2)	*Satisfactory (3-5)*	*Excellent (6-7)*
Curiosity / Recognizing and exploring a problem			
D1.1. Recognizing problems	Doesn't recognize a problem. Accepts things as they are. Perceptions have no consequences. "It is broken". No non-verbal signs of longing or interest.	Is attentive. Wants to know how things are made. States a desire or a problem on the basis of an observation or annoyance. "Couldn't that be better?"	Has an eye for things that can be improved. Is able to indicate why something is a problem that should be solved.
D1.2 Using previous knowledge	No signs that existing knowledge, skills or experiences are used.	Recognizes relations between a problem and previous experiences: "I have seen this before". Explicitly mentions relevant previous knowledge ("Trusses can make a bridge stronger").	Has knowledge on many subjects and shows this. Knows many existing solutions to technological problems.
D1.3 Problem exploration	Doesn't explore the problem. Is passive. Is not committed to the design task.	Explores intuitively. Looks; feels; uses sensorimotor experiences. Seeks on the internet or other sources. Tries to explain why the problem should be explored in this way.	Explores systematically. Can provide clear reasons for exploring this way. Is not afraid to try new ways. Has specific expectations. Poses focused questions. Finds good sources of information.
D1.4 Confining the problem	Doesn't bother whether the problem is too big or complicated for solving. Is guided by what is at hand.	Focuses on what is possible to achieve with one's capabilities.	Knows how to confine the problem. Is explicit about what is most and what is less important. Provides reasons for choices.
D1.5 Specifications	Doesn't take the requirement of a solution into account. Thinks about solutions	Can justify the solution to the problem with an appeal to specifications	Can take the user's point of view. Starts with formulating specifications. Takes constraints and

	without constraints or specifications.		circumstances into account.
Creativity / Designing solutions			
D2.1 Proposing a solution	Doesn't propose any ideas. Is not able to suggest a solution.	Proposes solutions. Is mainly inspired by existing solutions. Needs confirmation to continue on a track.	Uses the specifications to design solutions. Reasons in terms of function-form or means-goal. Proposes original and creative ideas.
D2.2 Choosing a solution	Provides no, or no good, reasons. Wants to do what is fun.	Provides at least one good reason for choosing a proposal.	Critically discusses the choice from the point of view of the specifications. Is explicit about disadvantages and possible trade-offs.
D2.3 Making a plan	Doesn't make a plan. Or, plans are sloppy, incomplete or incomprehensible to others	Makes an adequate plan that is comprehensible to other	Makes a detailed plan. Addresses all activities. Schedules. Is explicit about which materials, tools, et cetera to be used. Makes drawings.
Executive functions / Carries out the design			
D3.1 Use of materials and tools	Is unable to use the necessary materials or tools. Needs help.	Is able to use the necessary materials and tools.	Is skilful with materials and tools. Decides which materials or tools are most adequate. Provides reasons for choices.
D3.2 Making of the design	Is unable to make the artifact, even with help.	Is able to make the artifact, perhaps with some help. Sticks to the plan.	Is independent and careful. Has a repertoire of techniques. Is skilful. Solves problems.
Critical thinking / Testing and improving the design			
D4.1 Testing the design	Doesn't test the design systematically.	Checks whether the design meets the overall specifications. Judges in terms of 'yes' or 'no'.	Systematically checks whether the design meets all specifications. Is critical and nuanced. Repeats tests. Discovers the most

			important flaws and mistakes.
D4.2 Trouble shooting	Ignores or downplays problems. Doesn't look for causes or solutions. Doesn't propose suggestions that would improve the design.	Is aware of problems or mistakes. Proposes suggestions for improvement.	Understands and explains problems. Searches systematically for solutions. Uses previous knowledge. Has creative ideas for improvement.
D4.3 Redesign	Doesn't succeed to carry through improvements. Is easily discouraged.	Carries through improvements. Is eventually able to meet most specifications.	Solves all problems satisfactorily. Doesn't tinker. Keeps the integrity of the design.
Communicating			
D5.1 Giving a presentation	Is unable to give a presentation that outlines the problem, the proposed solution and an evaluation whether the design meets the specifications.	Is able to give a presentation that outlines the problem, the proposed solution and an evaluation whether the design meets the specifications.	Is able to clearly present the whole design process in word and writing. Adequately uses drawings, figures, graphs, and other data.
D5.2 Justification	Doesn't indicate whether the design meets the specifications or solves the problem. Just describes what is done or made.	Justifies the design in terms of solving the problem.	Is able to indicate the quality of the design and its components. Uses function-form and other argumentations. Indicates the possibilities for use and improvement.
D5.3 Sharing	Doesn't speak about the design. Is not involved.	Speaks when asked and spontaneously about the design. Mentions striking experiences.	Speaks spontaneously, with detail and with involvement about the design, the process, the product and the possibilities for use. Is fully committed.

Rubric Attitudes and generic skills	
A1 Enjoyment, interest and motivation	Students who enjoy inquiry and design are enthusiastic, show involvement, take initiative and talk spontaneously about what they are doing and thinking. For example, they engage in activities to find more information about the topic. They ask questions to themselves and to others.
A2 Initiative and executive functioning	Students who take initiative look for situations and possibilities to expand and apply their knowledge and skills. Students with good self-regulation skills manage to get along through the design cycle without much teacher support and intervention. They can plan, stick to the plan or change the plan when necessary. They feel responsible, focus on the
A3 Communicative and social attitudes	To be able to cooperate is not just a skill but also an attitude that can be enhanced through inquiry and design assignments. A student with a communicative and social attitude is interested in the contribution of others, listens attentively, is respectful, elaborates on what others do and say, pays attention to the process of decision making, shares ideas, employs the
A4 Creativity and innovation	Creative students have, more than others, the ability to come up with new ideas, explanations and solutions. They see relations and combinations that are not yet visible to others. They can think ‘out of the box’. They are more able than others to learn from examples and to utilize pre-knowledge and